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Research Article

Design and Analysis of Circular Fractal Array based Micro-strip Patch Antenna for Microwave Applications

Babita Harchandra†* and Randhir Singh†

†Department of E&C, Sri Sai College of Engineering & Technology, Badhani, Pathankot, Punjab- 145001, India

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Abstract

In this paper, we presented the design and analysis of micro-strip patch antenna with circular fractals that is suitable for different microwave frequency band applications. A reduction in physical size and multi-band capability are thus important design requirements for antennas in future wireless devices. Two different compact, multi-band circular fractal antenna designs are proposed to operate at different frequency bands in-between 1.0 GHz to 15.0 GHz. The design process consisted of initial theoretical calculations followed by extensive numerical simulations. ANSYS based high frequency structural simulator (HFSS) simulation software were used to design two micro circular fractal array antennas were implemented as micro-strip patches on printed circuit boards (PCB) and were found to perform in agreement with design expectations.

Keywords: F*ractal antenna, micro-strip patch, microwave, s-parameter, radiation pattern.*

1. Introduction

In this modern world of wireless communications, there has been tremendous demand for compact, light and portable communications systems (S. Arya *et al*, 2012) (S. Arya *et al*, 2012). In this regard, micro-antenna is one of the important components that act as trans-receiver in every wireless communications systems (R. Arora *et al*, 2014) (R. Arora *et al*, 2013). Among different types of micro-strip patch antennas, fractal antennas are studied during a decade. Some part of the fractal objects have the same shape as the whole object but at a different scale (J. P. Gianvittorio *et al*, 2002). The design of fractal shapes is carried out by applying an infinite number of times an iterative algorithm. The fractal geometry was first defined by B.Mandelbrot in 1975 (J. P. Gianvittorio *et al*, 2002). This describes complex geometries and was generated with an iterative procedure. By following this concept, there had been several reports proposed by various researchers with different fractal structures during recent times (C. Puente *et al*, 2001). Sierpinski fractal antenna is developed using triangular (gasket) filled shape, Koch snow-flake fractal antenna (B. Mirzapour *et al*, 2008) is based on the triangular curve and the Hilbert or Minkowski fractal antenna (K. J. Vinoy *et al*, 2010) design is on the basis of square curve. Several iterations are possible within fractals until the change in frequency is very small. Fractals can be used to miniaturize patch elements as well as wire elements, due to their space filling properties (R. L. Yadava *et al*, 2010). The advantages of fractal antennas are that it has relatively large effective length, but the profile form can generate a capacitance or inductance that can help for impedance matching the antenna to the circuit (J. Romeu *et al*, 2001) (Nathan Cohen, 2002), (Neetu *et al*, 2013). Fractal antennas acquire various shapes and forms. It has been revealed that fractal shapes radiate enough electromagnetic energy and posses several properties that are advantageous over other antenna types (S. Suganthi *et al*, 2012) (Vivek Ram *et al*, 2012) (H. O. Peitgen *et al*, 1990). They can be used as multi-band antennas, which can radiate signals at multiple frequency bands.

In this work, symmetrical and asymmetrical micro-strip circular fractal antenna array has been designed and studied. The radiation pattern of the symmetrical circular fractal antenna array clearly shows a better resemblance at different frequencies than those of the asymmetrical array. However, by changing the slight symmetry, the resonant frequency of the proposed fractal antennas changes effectively. This may due to change in the fractal wavelengths with respect to one another. The results obtained had showed better improvement in the return loss and radiation pattern for symmetrical arrays in-comparison to another one.

2. Antenna configuration

The design of the antenna is based on the wavelength, λ. The wavelength λ of the antenna is given by the equation

*Corresponding author: **Babita Harchandra**

$$\lambda = \frac{c}{f_0}$$

where c is the light velocity and f_0 is the resonant frequency. Consequently, the size of the antenna will increase as the resonant frequency decreases (C. A. Balanis, 1997). The fractal antenna is designed such to obtain a smaller size antenna that can operate at the same frequency.

The width, W and the length, L of the patch are calculated as

$$W = \frac{c}{2 f_0 \sqrt{\frac{(\varepsilon_r + 1)}{2}}}$$

$$L = \frac{c}{2 f_0 \sqrt{\varepsilon_{reff}}}$$

where ε_r is the dielectric constant and ε_{reff} is the effective dielectric constant and can be obtained by

$$E_{reff} = \frac{\varepsilon_r + 1}{2} + \left(\frac{\varepsilon_r - 1}{2}\right)\left[1 + 12\left(\frac{h}{W}\right)\right]^{-\frac{1}{2}}$$

where h is the height of the substrate.

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3. Antenna geometry

The proposed designs are simulated using HFSS software on the computational machine with processing speed of 2.6 GHz and 4 GB RAM. The virtual memory used during simulation is 2.6 GHz. Frequency domain analysis is selected while simulating the model. The designed antennas are then enclosed in the rectangular air box. The characteristic impedance (Z0) of the simulated designs is set at 50 Ω. Figure 1 and Figure 2 shows the geometries of two different designs selected to develop and analyze the micro-strip patch based fractal antennas.

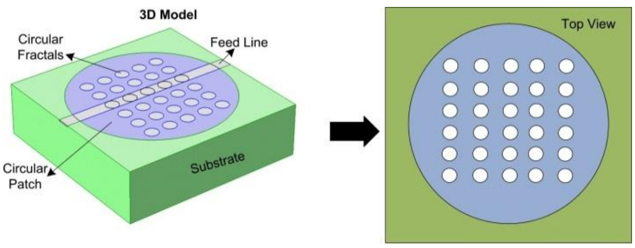

Fig.1 Schematic showing shape of the symmetrical fractal array antenna

Both designs consist of circular patch on the rectangular shaped substrate. The CPW (coplanar waveguide) feed system is used for both the designs. The dimensions of the proposed antennas are set using theoretical analysis.

The output parameters depend on the distance, position and the orientation of the inner circular fractals. The designs are developed by subtracting the inner circles from the circular patch. As shown in the diagrams, Fig 1 has symmetrical circles with equal radii while in Fig 2, the radii of circles are different, thus creating unique fractal design after subtraction from the circular patch.

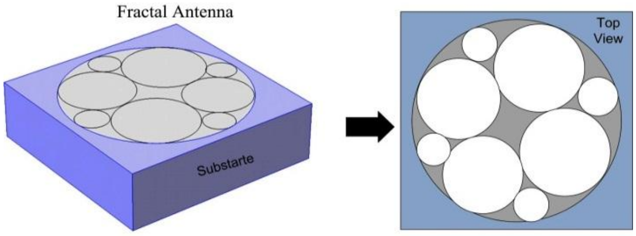

Fig.2 Schematic showing shape of the variable fractal array antenna

In Fig 1, fractals have same dimensions where as in Fig 2, the circular shaped geometry gives rise to different iterations. Table 1 shows parameters of the proposed designs with their dimensions.

Table 1 Experimental procedure parameters

Parameters	For same fractal array Dimensions (μm)	For varied fractal array Dimensions (μm)
Length of the substrate, L	100	100
Width of the substrate, W	100	100
Height of the substrate, h	25	25
Radius of patch, r_p	45	45
Length of CPW feed line	90	90
Width of CPW feed line	10	10
Radius of inner circular fractals	5	Bigger circles--11 Smaller circles--6

3. Results and discussions

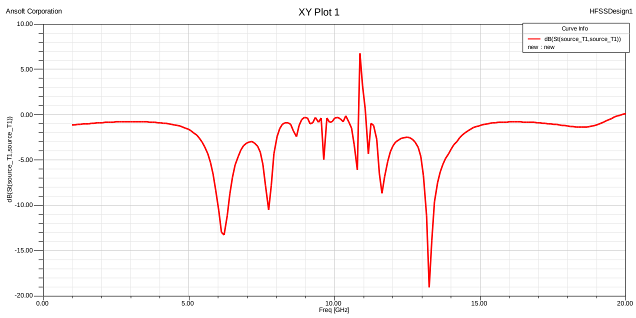

Fig.3 Insertion loss for symmetrical fractal array antenna

Figure 3 shows the plot for s-parameters for symmetrical fractal array antenna while Figure 4 shows the plot for variable fractal array antenna. Symmetrical circular fractal array based antenna shows satisfactory for triple frequency bands. The return loss at 6.2 GHz, 7.9 GHz and 13.25 GHz frequency is – 13.4 dB, -10.7 dB and -19.1 dB, respectively.

Similarly for varied dimensional fractals, the antenna shows successful emission of radiation at four different frequency regions. The return loss at 1.58 GHz is -21.0 dB. Similarly, the return losses at 4.46 GHz, 7.14 GHz and 8.06 GHz frequency is – 17.07 dB, 13.2 dB and -14.8 dB, respectively.

Fig.4 Insertion loss for variable fractal array antenna

Figure 5 and Figure 6 shows the radiation pattern for the above discussed antennas. From the radiated polar plots, it is clear that both antennas have almost same radiation pattern, but the symmetrical micro-strip fractal antenna has stronger field than the other one.

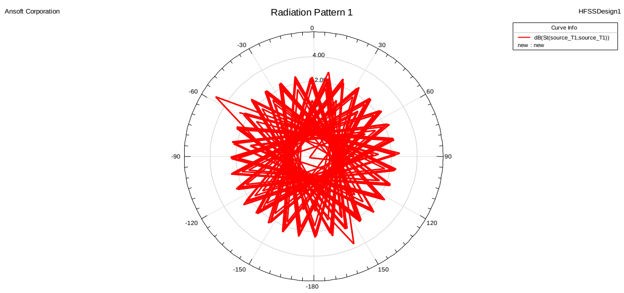

Fig.5 Radiation pattern of symmetrical fractal array antenna

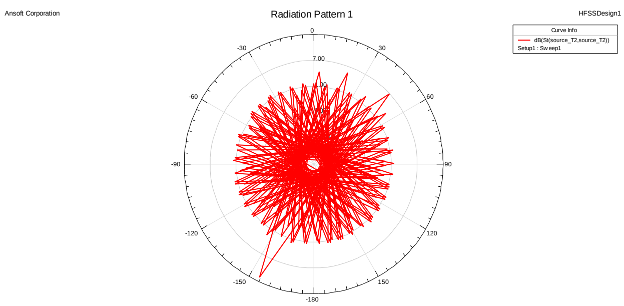

Fig.6 Radiation pattern of variable fractal array antenna

Figure 7 and figure 8 shows the gain in dB for symmetrical fractal and varied fractal array antenna, respectively. In an indirect way, these plots show the electrical field distribution.

The electric field distribution characteristics indicate that gain increases along z-axis but it reaches peak value at resonant frequencies. However, the results show little distortion also but the radiation patterns are reasonably well enough to work in different frequency bands.

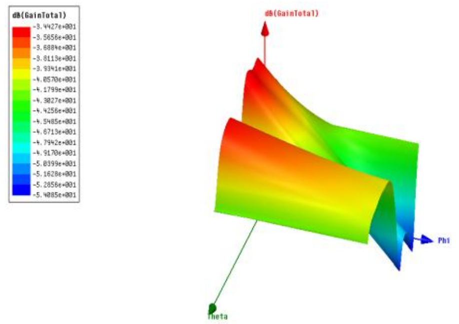

Fig.7 Antenna gain for symmetrical fractal array antenna

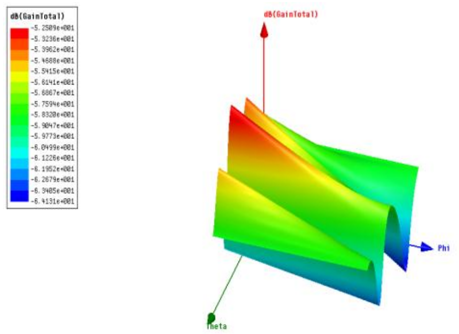

Fig.8 Antenna gain for variable fractal array antenna

Conclusions

In this paper, two different multi-frequency micro-strip fractal antennas are designed by using co-planar waveguide feed. The symmetrical fractal antenna shows better results at three different frequency regions in-between 5.0 GHz to 15 GHz frequency. The variable fractal shows satisfactory results at four different frequency regions in-between 1.0 GHz to 10 GHz. However, the symmetrical and equal circular fractal array antenna has better resonant frequency than the variable fractal antenna. This design is based on single layer fractals with circular patch and does not require complex circuitry. After evaluating the results, it is clear that the symmetrical fractal array shows better results than the variable fractal arrays. The characteristic impedance is fixed and accurate at 50 ohm. The density current distributions have a similar shape, thus explaining the similarity among both the patterns. The future work is to fabricate and test the performance for conformation and agreement with the simulated results.

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